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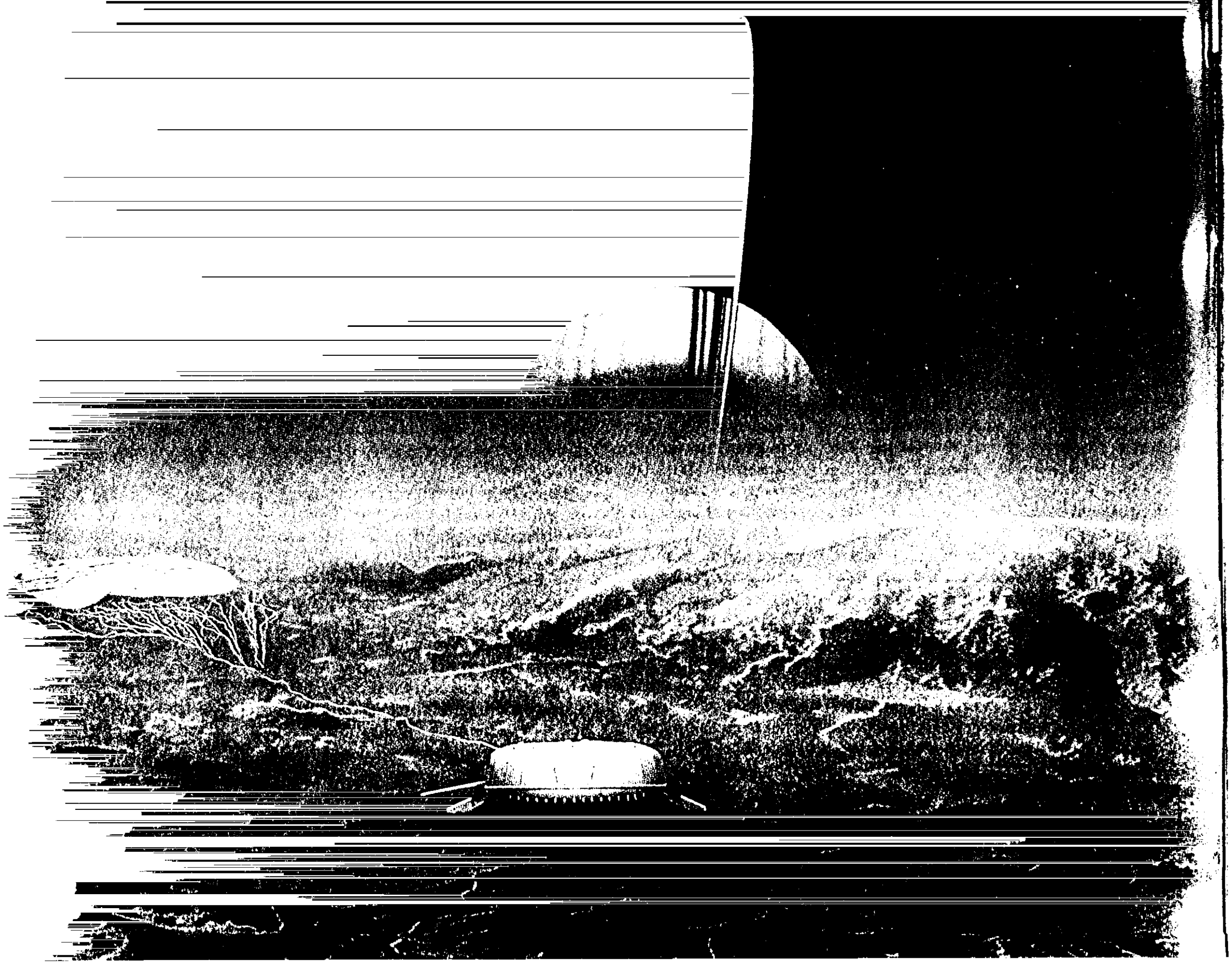
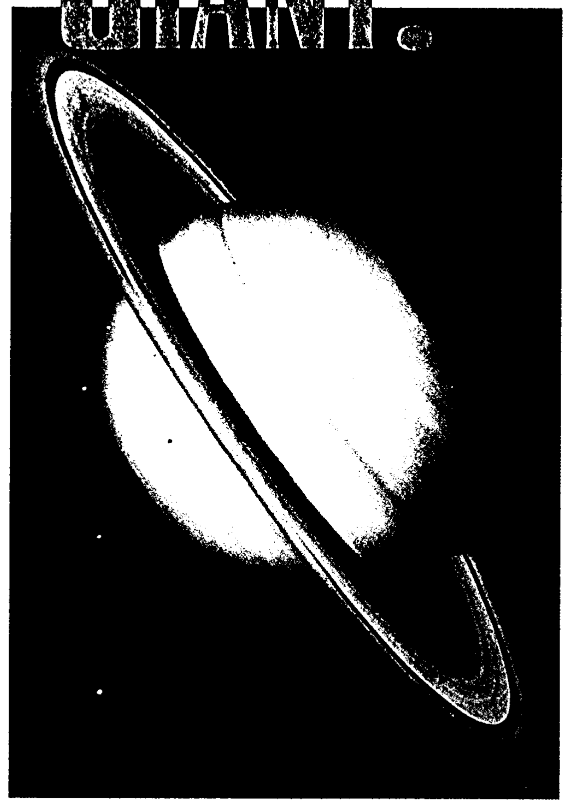


A MAJESTIC GIANT: THE CASSINI MISSION TO SATURN



ABOVE: This 1981 *Voyager 2* image shows Saturn's vast ring system, as well as three small icy moons and the shadow of a fourth. Reprocessed Image: USGS

LEFT: Although it is primarily designed to operate as it descends through Titan's atmosphere, the *Huygens* probe might survive its landing on the frigid moon. Titan's surface may hold lakes or oceans of liquid ethane and methane, sprinkled over a thin veneer of frozen methane and ammonia. The land surface and the ocean bottoms are believed to be covered by a deep layer of complex carbon compounds. Artistic license is used here to show Saturn, which may only be visible at infrared wavelengths from the surface.
Painting courtesy of the European Space Agency

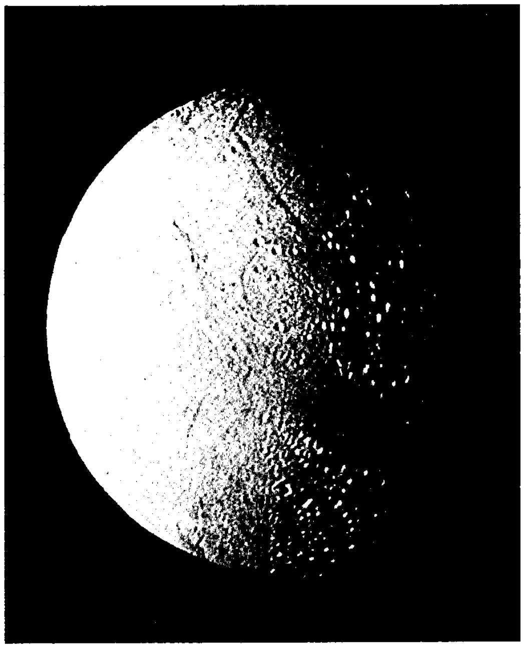
by Charley Kohlhase

In October of 1997, a two-story-tall robotic spacecraft will begin a journey of many years to the vast and exciting realm of Saturn. With a mass of roughly 2,500 kilograms (5,510 pounds) of dry hardware and 3,000 kilograms (6,615 pounds) of propellant, it needs a boost from the *Titan IV/Centaur* launch vehicle and several planetary gravity assists. Both are needed if *Cassini* is to reach Saturn with sufficient propellant to brake into Saturn orbit and accomplish its mission: to deliver a European-built probe to the large, hazy moon Titan, and then tour the saturnian system for nearly four years.

The *Cassini* mission has been undertaken by NASA, the European Space Agency (ESA) and the Italian Space Agency (ASI). It is named in honor of the French–Italian astronomer Jean Dominique Cassini, who discovered the prominent gap in Saturn's main rings (now called the Cassini division), as well as the icy moons Iapetus, Rhea, Tethys and Dione.

The probe that *Cassini* will deliver to Titan is named for Dutch scientist Christian Huygens. Using improved optics, he found in 1659 that the strange "arms" noted decades earlier by Galileo were actually a set of rings. While observing Saturn, Huygens also discovered the moon Titan, hence the choice of his name by ESA.

During its descent and possibly for a short time on Titan's surface, *Huygens* will beam data to the orbiter for storage and subsequent relay to Earth. Once these valuable data are safely received on Earth,



The face of Saturn's moon Enceladus is relatively smooth, largely uncratered and coated with unusually pure water ice. The particle density in Saturn's E ring increases near Enceladus' orbit. These two clues suggest that there might be a connection: Could geysers of water from Enceladus be feeding the E ring? Cassini may find the answer to this intriguing question.

Image: JPL/NASA

the orbiter will begin to intensively use its three dozen scientific sensors to examine the vast Saturn system.

Saturn

Saturn is one of the four ringed gas giants in our solar system. It is second in size only to Jupiter, but is considerably larger than Uranus and Neptune. With a diameter nearly 10 times that of Earth, it would enclose more than 750 Earths—but with a density less than that of water, it would float in an ocean of water, were there one big enough to hold it.

Unlike the inner planets, Saturn does not have a rocky surface but is made of gases. Hydrogen and helium predominate, but methane, ammonia, acetylene, propane and phosphine have also been detected. The gases become denser and hotter as one descends from the cloud tops to the interior.

We see Saturn as banded in pastel yellows and grays. Interestingly, the colors of the four gas giants differ, partly as a result of their varying distances from the Sun (and hence their temperatures). Jupiter's colors run toward tans and reds, and the more distant Uranus and Neptune appear as shades of pale blue.

Saturn radiates about 80 percent more energy than it receives from the Sun, but this cannot be attributed to primordial heat loss, as is speculated for the more massive Jupiter. One explanation has its basis in data obtained by the *Voyagers*. They found much less helium in Saturn's outer atmosphere than in Jupiter's. Perhaps the missing helium, long ago condensed out of the cool upper atmosphere, has been sinking slowly toward the planet's interior, converting gravitational energy to heat when the fall of the helium raindrops is eventually stopped.

The Amazing Rings

The rings of Saturn are a frigid cast of trillions of particles and icebergs, ranging in size from that of fine dust to that of a house. They march in orbits around their captor in a vast sheet of amazing expanse and thinness. It is believed that the ring fragments are primarily loosely packed snowballs of water ice, but slight colorations suggest that there are small amounts of rocky material, possibly even traces of rust.

Although the distance from the inner edge of the C ring to the outer edge of the A ring is about 13 times the distance across the United States, the thickness of the ring disk is not more than 10 to 30 meters (about 35 to 100 feet), with waves or "corrugations" in this sheet rising and falling by a couple of kilometers. If a model of the ring sheet were to be made from material about the thickness of a coin, its diameter would need to be at least 15 kilometers, or nearly 10 miles!

Numerous patterns, both simple and complex, are formed within this rotating sea of icy fragments. They are variously described as circular rings, eccentric rings, kinky rings, clumpy rings, resonance gaps, spokes, spiral density waves, bending waves and shepherding moons; there are, no doubt, tiny moonlets too small for the *Voyager* cameras to have detected. The elaborate choreography of this complex ring system of patterns is produced and orchestrated by the combined gravitational tugs from Saturn and its moons that lie out beyond the ring sheet, as well as by the tiny tugs and gentle collisions between neighboring particles.

How did the rings form in the first place? If one could collect all of the particles and icebergs into a single sphere, its diameter would not exceed about 300 kilometers (185 miles), roughly midway between the sizes of the moons Mimas and Phoebe. Are the rings simply leftover material that never formed into larger bodies when Saturn and its moons condensed aeons ago? Or, as suggested by the *Voyager* data, are they the shattered debris of moons broken apart by meteor impacts? If the impact theory is valid, small orbiting "ring moons" may be awaiting that moment when they too will be struck and transformed into magnificent rings. *Cassini* may well provide definitive answers to this puzzle.

Titan

Of Saturn's dozen and a half or so icy moons, Titan is not only the largest but also the most intriguing. Its dense atmosphere hides a frigid landscape that may contain lakes or oceans of liquid ethane and methane sprinkled over a thin veneer of frozen methane and frozen ammonia, which in turn probably overlies a mantle of frozen water ice. Are there really oceans on Titan? Some scientific arguments say yes, but radar bounces from Earth seem to say no, or at least not everywhere.

Scientists are fascinated by Titan's

brownish-orange haze, which is believed to be made of complex organic (carbon-based) molecules. They are formed in Titan's atmosphere by the bombardment of nitrogen and methane molecules by ultraviolet radiation and high-energy particles. Further reactions can lead to such chemicals as methylene, acetylene, hydrogen cyanide, cyanogen, and other complex molecules.

Containing carbon, these complex organic molecules would clump together into larger particles, raining slowly down on the alien surface below. If this process has been going on for a few billion years, the accumulated layer could be as deep as several hundred meters! It is true that organic molecules provide basic building blocks for life, but they are not necessarily produced by life. And even though the Titan environment may resemble the chemical factory of primordial Earth, scientists expect it to be lifeless due to the extreme cold. But perhaps *Cassini* can still shed light on the chemistry of early Earth.

Saturn's Other Moons

Titan may be Saturn's most intriguing satellite, but several of the smaller moons have their own peculiar mysteries. The surface of Enceladus is coated with unusually pure water ice, but much of this surface is smooth and uncratered. Also, Saturn's distant E ring has an increased particle density in the vicinity of Enceladus' orbit. What do these clues tell us? Could tidal stresses have heated the moon's interior and melted much of the surface, erasing most of the early impact craters? Could they even have created geysers of water or water ice to feed the E ring?

Iapetus is equally interesting. Dark as asphalt on its leading face (as it orbits the planet) and bright as snow on its trailing face, it perplexed early astronomers by disappearing on the left side (approaching the observer) of Saturn and reappearing on the right side. Arthur C. Clarke chose to feature this moon in his novel *2001: A Space Odyssey*, with its famous journey to the "eye of Iapetus," as it reminded him of a beacon. Was the dark material swept up from the outside, or did it rise up from the moon's interior?

Many of the other saturnian moons have their own telltale features, whether they be large impact craters (Mimas and Tethys), long trenches

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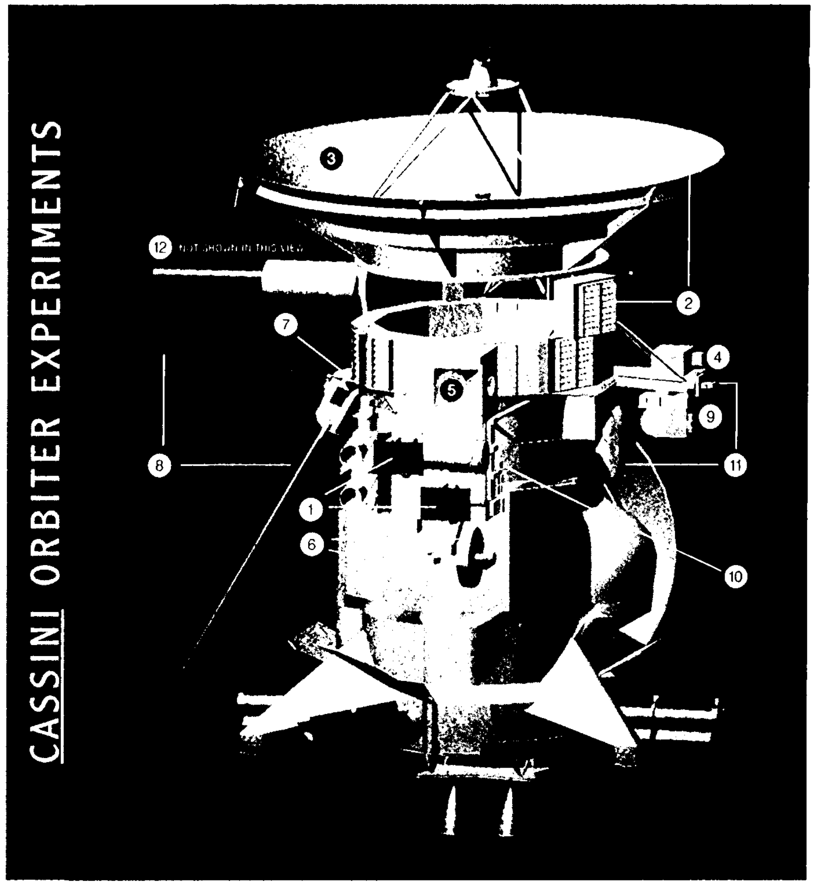
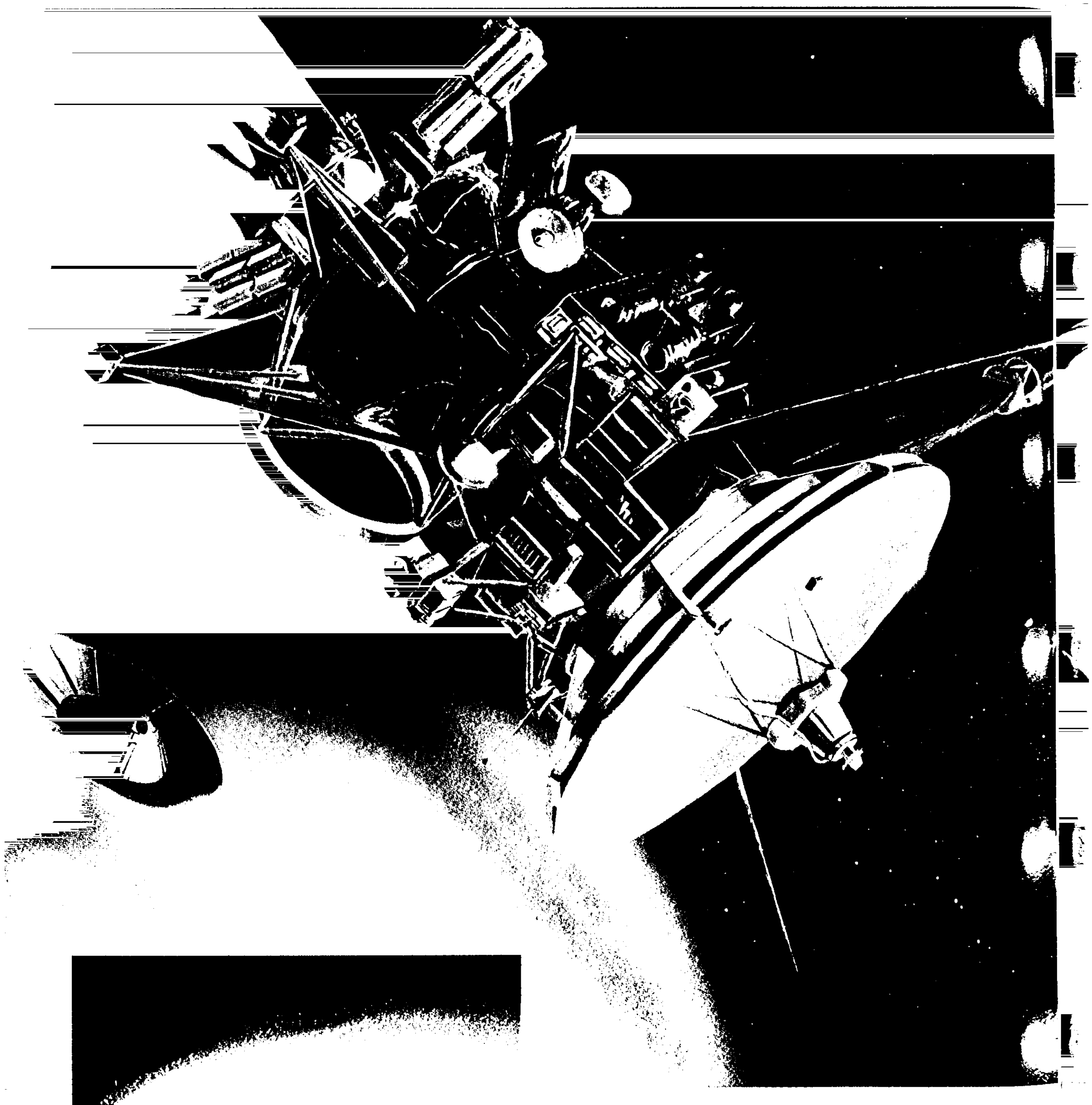


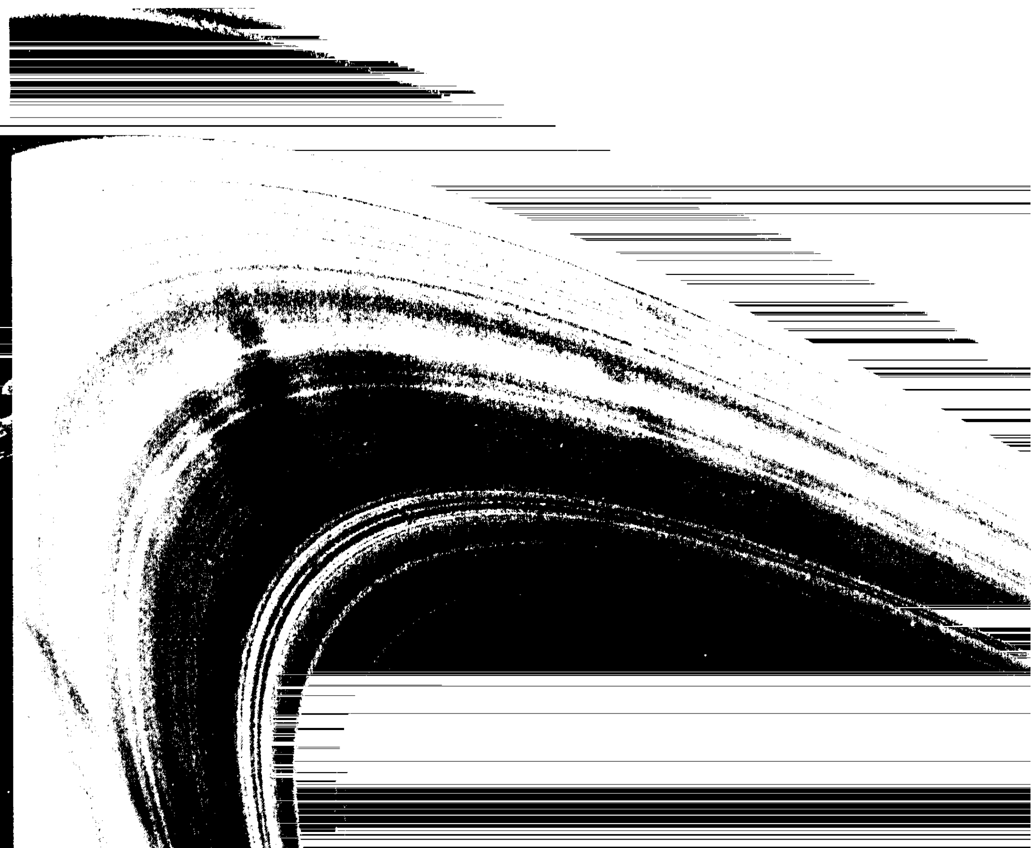
1. **Imaging Science Subsystem** takes photos in visible, near-ultraviolet and near-infrared light.
2. **Radar** maps surface of Titan using radar imager to pierce veil of haze. Also used to measure heights of surface features.
3. **Radio Science Subsystem** searches for gravitational waves in the universe; studies the atmosphere, rings and gravity fields of Saturn and its moons by measuring telltale changes in radio waves sent from the spacecraft.
4. **Ion and Neutral Mass Spectrometer** examines neutral and charged particles near Titan, Saturn and the icy satellites to learn more about their extended atmospheres and ionospheres.
5. **Visual and Infrared Mapping Spectrometer** identifies the chemical composition of the surfaces, atmospheres and rings of Saturn and its moons by measuring frequencies of visible light and infrared energy given off by them.
6. **Composite Infrared Spectrometer** measures infrared energy from the surfaces, atmospheres and rings of Saturn and its moons to study their temperature and composition.
7. **Cosmic Dust Analyzer** studies ice and dust grains in and near the Saturn system.
8. **Radio and Plasma Wave Science** investigates plasma waves (generated by ionized gases flowing out from the Sun or ions trapped by Saturn's magnetic field), natural emissions of radio energy and dust.
9. **Cassini Plasma Spectrometer** explores plasma (highly ionized gas) within and near Saturn's magnetic field.
10. **Ultraviolet Imaging Spectrograph** measures ultraviolet energy from atmospheres and rings to study their structure, chemistry and composition.
11. **Magnetospheric Imaging Instrument** images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind, a flow of ionized gases streaming out from the Sun.
12. **Dual Technique Magnetometer** describes Saturn's magnetic field and its interactions with the solar wind, the rings and the moons of Saturn.

Illustration: JPL/NASA



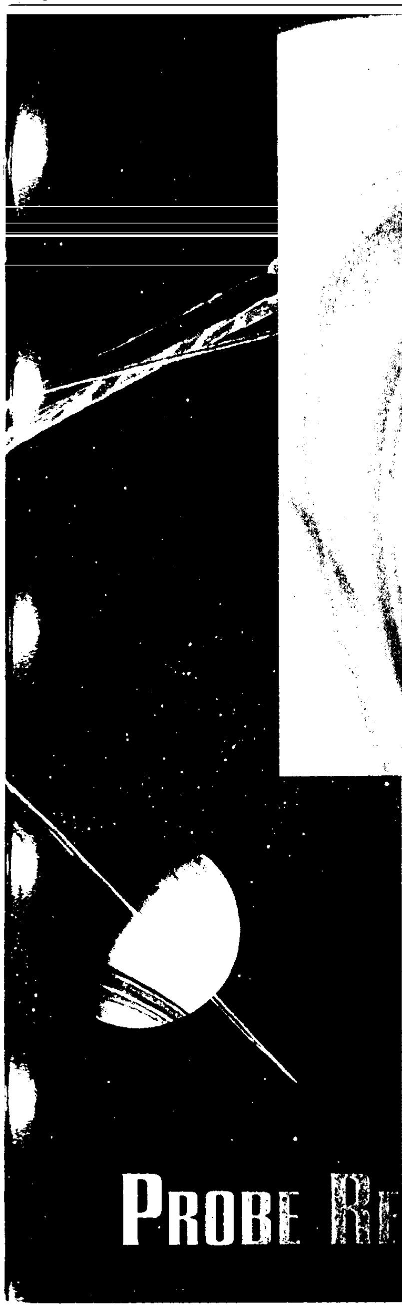
TITAN

Titan's chiefly nitrogen atmosphere is colored brownish orange from what are believed to be complex carbon-based molecules. Over aeons, these molecules have been forming, clumping into larger particles and slowly falling to the surface below. Image: JPL/NASA



THE SPOKES

Dark spokes form rapidly in Saturn's dense B ring, covering distances of several thousand kilometers in minutes. Scientists believe that meteor impacts with ring fragments produce clouds of charged dust, which are accelerated by Saturn's magnetic field, stirring up fine ring dust to form the spokes seen in this Voyager 2 *image taken in August 1981.* *Image: JPL/NASA*



PROBE RELEASE

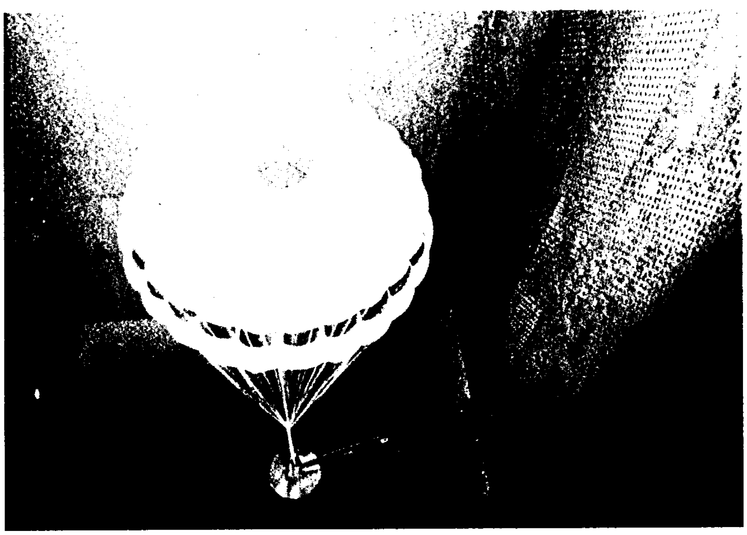
After releasing the Huygens *probe for descent through the atmosphere of the large moon Titan,* Cassini *will explore Saturn's neighborhood for nearly four years.* *Painting: Michael Carroll*

(continued from page 7)
(Tethys), or perhaps smaller moons in the same orbit (Tethys and Dione). All in all, these icy moons are members of an interesting club, which *Cassini* plans to explore with its broad array of sensors.

The Cassini Mission

Launch energies to go directly from Earth to Saturn are very great, so we must select launch times when other planets are in favorable positions in reach Jupiter. This also allows the trajectory experts to find more launch opportunities and, when Jupiter is out of position, to occasionally find a long-trip-time, less attractive route if need be.

The primary launch period for *Cassini* opens on October 6, 1997, and lasts for three to four weeks. Following gravity-assist swing-bys of Venus (twice), Earth and Jupiter, *Cassini* arrives at Saturn in June of 2004, firing its liquid rocket engine for an hour and a half to



A scale model of the* Huygens *probe, fitted with scaled parachutes, was recently tested in the transonic wind tunnel at Arnold Air Force Base in Tennessee. The results will be used to verify that the parachute and probe combination will work as designed at Titan. *Photograph: Arnold Engineering Development Center*

their orbits around the Sun to permit them to be used as gravity-assist swing-by bodies by *Cassini* to gain speed (relative to the Sun). In the technique of gravity assist, a spacecraft and swing-by body can mutually gain or lose speed relative to a central body they are both orbiting. Jupiter has the greatest mass for gravity assist, but its position relative to Saturn is favorable only once every 20 years, actually for about a one-month launch period in each of three successive years; the pattern repeats itself 20 years later.

The *Titan IV/Centaur* is very powerful, but it cannot boost the heavy *Cassini* spacecraft directly to Jupiter. It is possible, however, to first launch the spacecraft either to Venus or to an Earth-return swing-by so that it may pick up the added speed needed to brake into Saturn orbit, setting up the delivery of the *Huygens* probe to Titan some five months later.

After recovery and playback of the *Huygens* probe data, the orbiter will continue on its tour, making some five dozen orbits about the planet. During this tour, it will use precision navigation to achieve more than 30 close encounters with Titan, at least four close encounters with icy moons of high interest, such as Enceladus and Iapetus, and two dozen more distant flybys of other moons. Through the use of Titan gravity assists, with Saturn as the central body, *Cassini*'s orbits will be varied to permit excellent viewing of equatorial and polar zones, including the huge but invisible magnetosphere of energetic particles trapped by Saturn's magnetic field.

Because scan platforms were eliminated to reduce costs, the entire spacecraft must turn to point the cameras and other sensors at particular targets. More than half of each Earth day will be spent maneuvering to the desired pointing attitudes and collecting scientific data on the solid-state recorders. For the rest of the day, *Cassini* will point at Earth and play back the recorded data.

International Cooperation

A sizable international team is designing, building and flying the *Cassini* spacecraft. In addition to some 1,300 academic and industrial partners in 16 European countries, there are more than 3,000 people scattered across 32 different states in the US.

The mission is managed for NASA by the Jet Propulsion Laboratory in Pasadena, California, where the *Cassini* orbiter is being designed and assembled. A team based at ESA's European Space Technology and Research Center (ESTEC) in Noordwijk, the Netherlands, is managing development of *Huygens*.

Although most of the orbiter and probe hardware comes from within their respective countries, key items are produced elsewhere. The Italian Space Agency is contributing the orbiter's 4-meter-diameter (13-foot) high-gain antenna for communications, as well as significant portions of three orbiter science experiments. On the other hand, the US is supplying the batteries and two science instruments for *Huygens*.

The Cassini Orbiter

The orbiter is a large and sophisticated collection of high-quality hardware and software, integrated very carefully to meet a special challenge. Its primary purpose is to carry the many scientific sensors to the Saturn system and provide them with such essential services as power, attitude control and pointing, sequencing, environmental control, precision navigation, and data collection and broadcast to Earth.

The orbiter design is the result of years of brainstorming and performance trade-offs, subject of course to budget limitations. New technology is also folded in by way of such advances as solid-state data recorders with no moving parts, very high speed integrated circuit (VHSIC) chips and powerful application-specific integrated circuit (ASIC) parts for onboard computers, and reliable solid-state power switches to eliminate transients that usually occur with conventional power switches.

Cassini can provide over 650 watts of power to its engineering and scientific subsystems. It can point its sensors to accuracies of a tenth of a degree and maintain stability levels over 10 times slower than the motion of a clock's hour hand. It can control subsystem temperature levels to between 10 degrees and 40 degrees Celsius (50 and 104 degrees Fahrenheit), navigate to accuracies of 30 kilometers (about 20 miles), store some 4 billion binary bits of information, and broadcast data to Earth at rates as high as 140,000 bits per second.

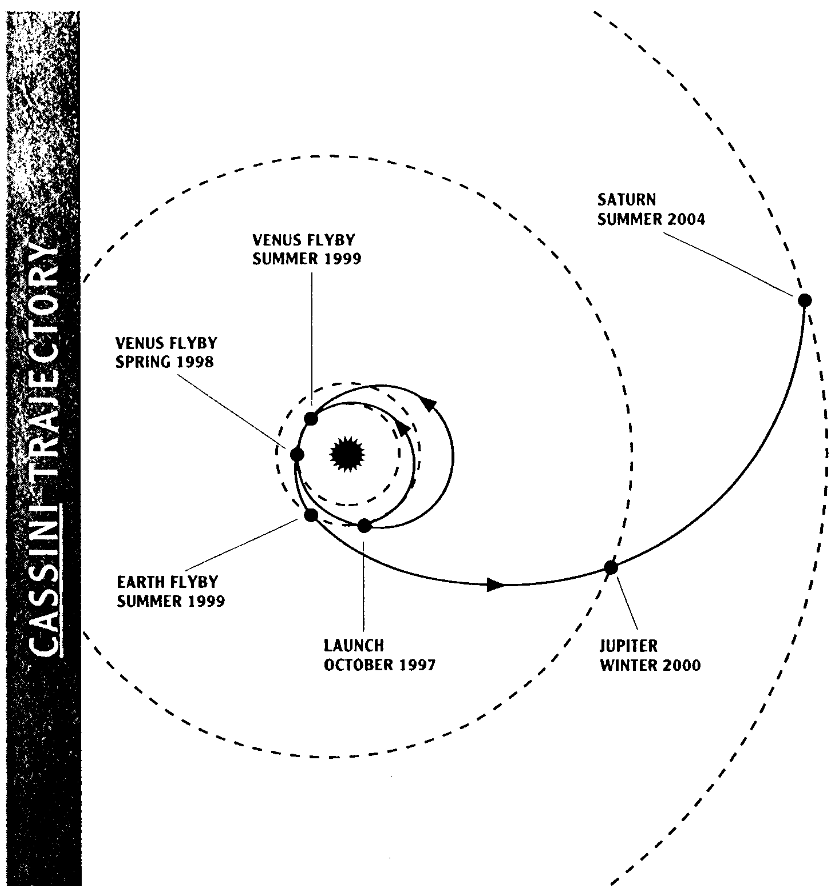
The Huygens Probe

The 2.7-meter-diameter (8.9-foot) probe will enter Titan's atmosphere at about 6 kilometers per second (over 13,000 miles per hour). It will use a silica-based, shuttle-tile-like heat shield to dissipate a heat-energy input of 35 kilowatt-hours in less than a minute, reaching temperatures on its ablative front surface as high as 1,700 degrees Celsius (over 3,000 degrees Fahrenheit) in the process.

Shortly thereafter, the main parachute, which is 8.5 meters (27.9 feet) in diameter, is deployed at an altitude of 170 kilometers (105 miles), followed 30 seconds later by the release of the heat shield and its supporting structure, allowing the central module of scientific sensors to descend slowly through the murky atmosphere. At an altitude near 110 kilometers (68 miles), the main chute is released and a smaller drogue chute provides stability for the remaining descent to the alien surface.

The probe carries accelerometers to measure drag forces in the upper stratosphere, as well as other sensors to measure temperature and pressure. It will also carry an instrument to measure the structure and physical properties of the atmosphere, an aerosol collector and pyrolyzer to examine clouds and suspended particles, a gas chromatograph and mass spectrometer to measure the chemical composition of gases and particles in the atmosphere, a Doppler wind experiment to study the effects of winds on the probe, and a descent imager and spectral radiometer to take pictures of Titan's clouds and surface and to measure temperatures of particles in the atmosphere.

The probe's primary mission is conducted during its atmospheric descent of 2 to 2.5 hours, but there is always the chance that it might survive touchdown, given a landing speed of only 5 meters per second (about 11 miles per hour). If it doesn't tip over too far, and if it can continue to function on battery power until the orbiter flies over the horizon, it may be able to use the instruments in its surface science package to tell us more about that surface. Its tiltmeter can measure wave motion if it lands in liquid, and another device will be able to measure the liquid's index of refraction. A sounder can give readings of liquid depths of less than a kilometer.



Cassini's almost seven-year-long journey to Saturn uses gravity assists from Venus, Earth and Jupiter to deliver the large spacecraft. *Chart: JPL/NASA*

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If the *Cassini* mission goes as planned, its results should provide an exciting trail of discoveries and new understanding as the first decade in the next century winds down. All people who love to gaze at the stars and ponder the nature of other planetary realms will have much new food for thought. Theories about the evolution of the solar system and chemical processes on primordial Earth may be improved.

Bright young students will be inspired to devote their professional lives to one of the pure sciences or perhaps to the engineering challenges of the future. Indeed, nations that diversify in facing the future, choosing to meet both basic needs and exploratory pursuits, will gain strength from the process.

Charley Kohlhase is science and project engineering manager for the Cassini *mission to Saturn. Outside work, he is active in wilderness preservation and photography.*